Forming of cast Fe – 45 at. % Al alloy with high content of carbon

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Abstract

The iron aluminide containing 45 at. % Al, 4 at. % C and 1 at. % Si (Pyroferal) was considered as a structural material without any possibility of forming. The brittle character of the material is the reason for cleavage, which takes place on the surface or in the whole volume of the casting during forming, even at high temperatures. A special rolling procedure of such material is newly described, which enables to roll the casting at high temperatures. The sample is enclosed with a special can to prevent the direct contact of the cold rolls with the surface of the hot casting. The positive effect of the can is documented and the structure of the rolled sample (FeAl + Al_4C_3 composite) is described.

Key words: A. iron aluminides based on FeAl; B. precipitates; C. plastic forming, hot; C. rolling

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Introduction

Pyroferal is the iron aluminide (44–47 at. % Al), alloyed with 4 at. % carbon and 1 at. % silicon [1]. This alloy was used in the fifties of the last century in the former Czechoslovakia to replace the cast iron, highly alloyed by chromium and nickel. Only recently the reasons of the excellent high temperature mechanical and corrosion-resistant properties were studied [2,3]. The formation of the aluminium carbide Al_4C_3 is connected with the presence of Si. The material behaves like a very hard composite structure. Casting to the final form of the product has been used as the only processing of this material [4,5]. According to investigations of e.g. Palm and Inden [6], the occurrence of this carbide is not expected in this part of the ternary

Fe-Al-C diagram, i.e. far from the Al-C line. These authors identified two-phase material α-FeAl + C (graphite). By contrast, Ohtani et al. [7] found using CALPHAD a mixture of α-FeAl + Al_4C_3 under the same conditions. Recently also the Fe_3Al-type aluminides were used to be hardened by carbon (~ 4-5 at. %), see e.g [8]. In such cases also κ-carbide Fe_3AlC appears.

The aim of the presented paper is to describe the hot rolling of this material, which prevents effectively fraying and cracking, caused by the thermal shocks arising at the surface of the hot casting when it comes into the contact with the cold rolls. This basically changes the general view that Pyroferal is applicable only in cases if no forming of the casting is necessary. This opens up new possibilities for application since its properties are very good (e.g. high temperature corrosion properties etc.) [1].

Experimental procedures

The composition of the tested material is as follows: Fe – 45.02/29.7 Al – 4.02/1.18 C – 0.7/0.48 Si (in at. %/wt. %). The rectangular sample (with thickness 19.5 mm x width 35 mm x length 100 mm) was obtained by melting and casting in the vacuum laboratory furnace, using ultrasound that improves the chemical and structural homogeneity of the casting [9].

The rolling procedure used for this material has been patented [10]. The sample is placed into a special can. The reason for its use is to prevent the nucleation of cracks on the surface of the hot rolled casting. Two factors are important:

- The walls of the can prevent the direct contact of the cold work rolls with the surface of the hot rolled casting. Thus no substantial cooling of the surface of the rolled material takes place.
- The unfavourable shear stresses originate in this case on the contact surface of the can wall, and not on the surface of the material of Pyroferal type with extremely low plasticity.

It is evident that a very close agreement of the deformation behaviour of both materials, i.e. of the protective can and of the rolled material (Pyroferal type) must exist. After some optimization experiments, the corrosion-resistant ferritic chromium steel X6Cr17 was applied for the protective can, which is prepared by bending and welding of a sheet with thickness 2 mm. The can design prevents from the undesirable spread of the rolled sample. Attention is paid to the appropriate location of the vent ports in the corners of the can, through which the hot air can safely escape during the heating and proper forming.

The castings packed in the can were rolled in the laboratory four-high mill K350 [11]. The samples were heated to 1230 °C in the laboratory furnace without any protective atmosphere.

The peripheral speed of the work rolls with diameter 67 mm was 80 rpm. Five reverse double-passes with interpass times of 5 to 7 s were used. After each couple of reductions the samples was heated to 1230 °C for 120 s (after the 1st and 2nd double-pass), for 150 s (after the 3rd double-pass) and 180 s (after the 4th double-pass). The relative height reductions were 10 % for the 1st and 2nd pass, 13 % for the 3rd and 4th pass and 15 % for passes Nos. 5 to 10. The final thicknesses determined after the removal of the can were the following: the iron aluminide 4.5 mm, i.e. total reduction 77 %; the protective sheet 0.5 mm, i.e. total reduction 75 %. The final rolled product was cooled in the free air.

The high temperature of processing prevented also the start of the chemical reaction of the carbides with moisture [12]:

$Al_4C_3 + 12\ H_2O = 4\ Al(OH)_3 + 3\ CH_4$,

which deteriorates the quality of the material due to cracking. Therefore, in normal atmospheric conditions at the room temperature this material must be kept under the protective oil film [13].

Results and discussion

To confirm the effect of the can, a part of the weld on one end of the sample was intentionally performed as not perfect to initiate a rupture of the can and enable the comparison of the deformation of the surface layers with and without the protection by the can (see Fig. 1).

The surface of the rolled sample is not perfectly plane, but in the places covered by the protective can it is totally without any surface cracks. On the other hand, when the can was advisedly unseamed during the last two reductions and the immediate contact of the iron aluminide with the rolls occurred, the related place lost the temperature quickly and heavy cracking developed on the surface.

The phase composition of this alloy as given in the phase diagram [7] (see Fig. 2) is iron aluminide FeAl plus aluminium carbide Al_4C_3, which was identified by X-ray diffraction. The distribution of Al_4C_3 particles (needles and plates) in the casting was partly heterogeneous. They appear in the alloy in the more or less dense arrangement (see Fig. 3).

The microstructure of the final rolled product is shown in Fig. 4. The arrangement of Al_4C_3 particles in the micro-volume (see Fig. 4a) indicates heterogeneity of the metal flow during the plastic deformation. Under given conditions, the Al_4C_3 particles are non-deformable, they do not change either their shape, or their size. Nevertheless, due to the different deformation behaviour of the metallic matrix, their mutual distance in the direction of thickness of the rolled product decreases.

Revealing of grain boundaries by the conventional metallographic procedures was very difficult. Therefore, the electron backscattered diffraction (EBSD) was used, see Fig. 4b. The microstructure after forming is rather heterogeneous after the described procedure. It includes partly the large grains of α-FeAl extended in the rolling direction, partly a quantity of the relatively fine equiaxed grains. This may indicate the unfinished development of the static recrystallization during free cooling of the final rolled product. The repeated grain refinement by recrystallization can also be presumed during the reheating of the rolling stock in the furnace after each even pass.

Conclusions

- The special canning technique was utilized newly for essentially high brittle material (cast Pyroferal Fe – 45 at. % Al – 4 at. % C – 1 at. % Si). The alloy was successfully hot rolled under specific conditions. The material was repeatedly heated to 1230 °C and total height reduction of 77 % was reached without cracking.
- The multi-pass laboratory rolling was enabled by the application of the can, welded from the corrosion-resistant ferritic chromium steel X6Cr17. This prevented cleavage of the rolling stock both on the surface and in the volume.
- The structure of the final product was partly recrystallized and heterogeneous (with respect to the size and to the shape of grains). The object of the future research will be to find subsequent annealing processes, which initiate recrystallization to homogeneous fine-grained microstructure of the hot-rolled Pyroferal.

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Figure captions

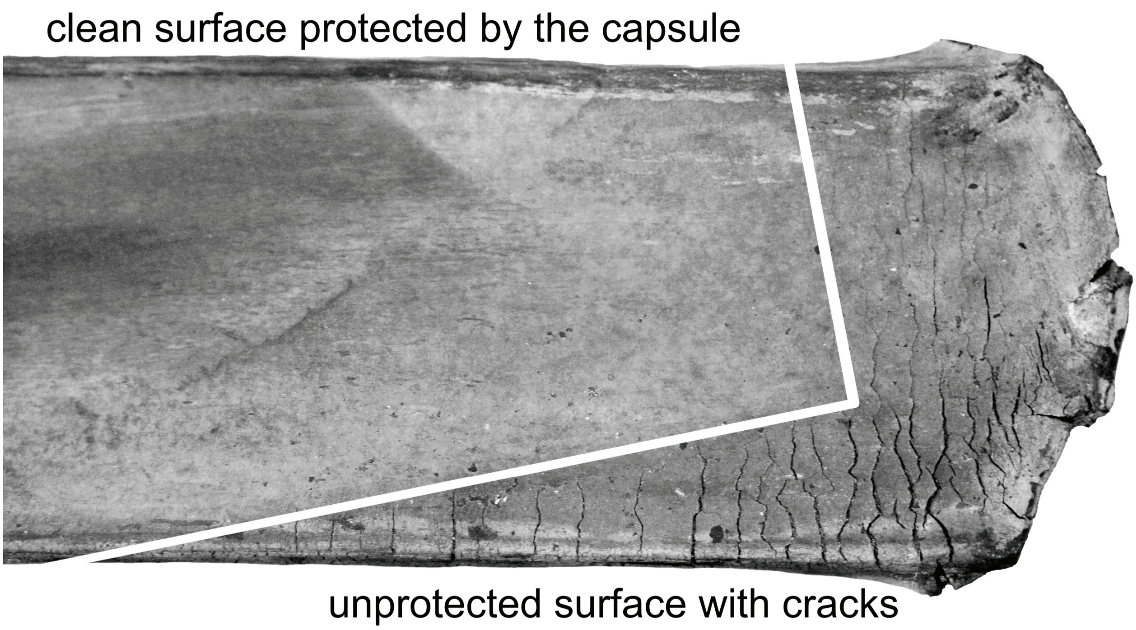


Fig. 1 The final rolled stock after removal of the protective can

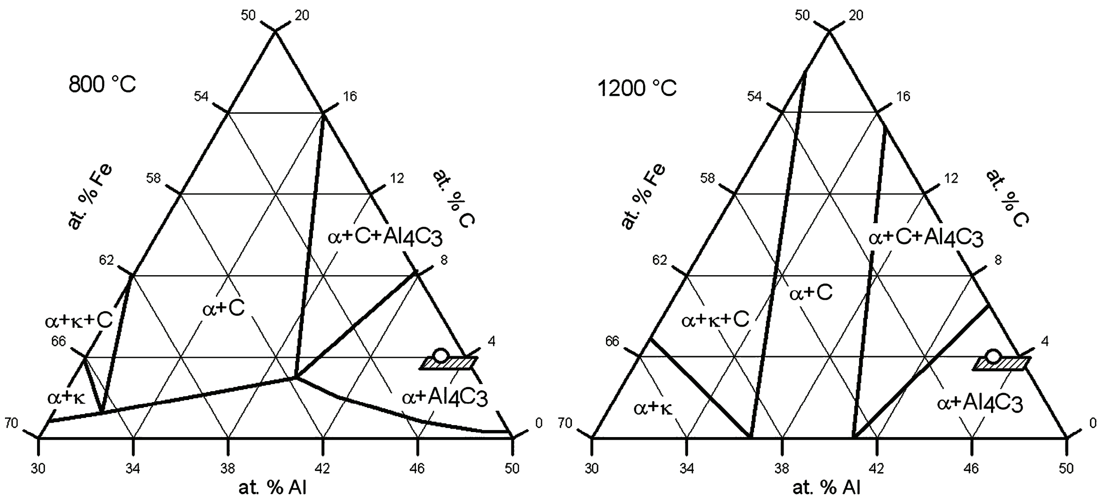


Fig. 2 Fe – Al – C phase diagram for 800 and 1200 °C (according to [7]); approximate composition range of the Pyroferal alloy is indicated by the rectangle

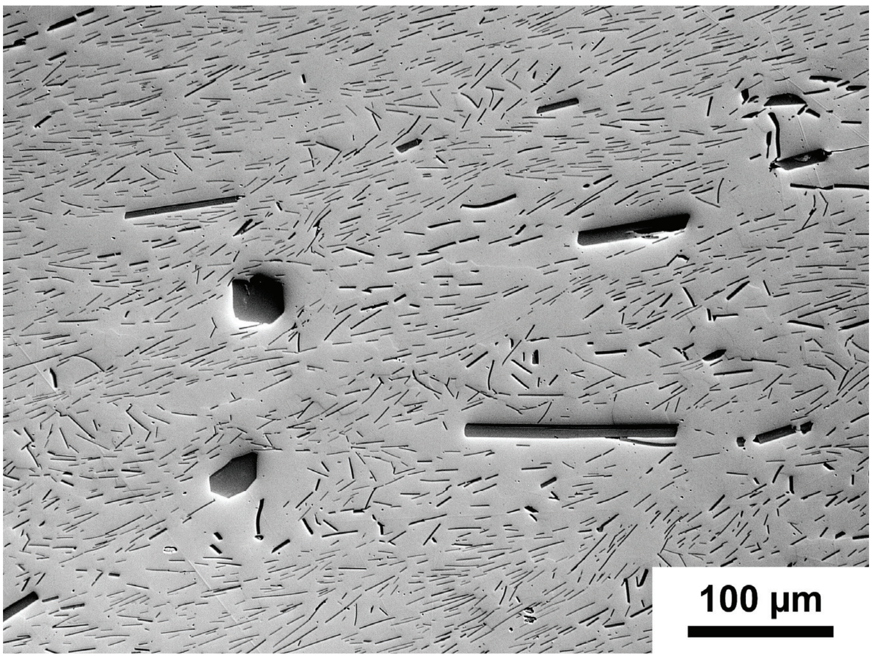
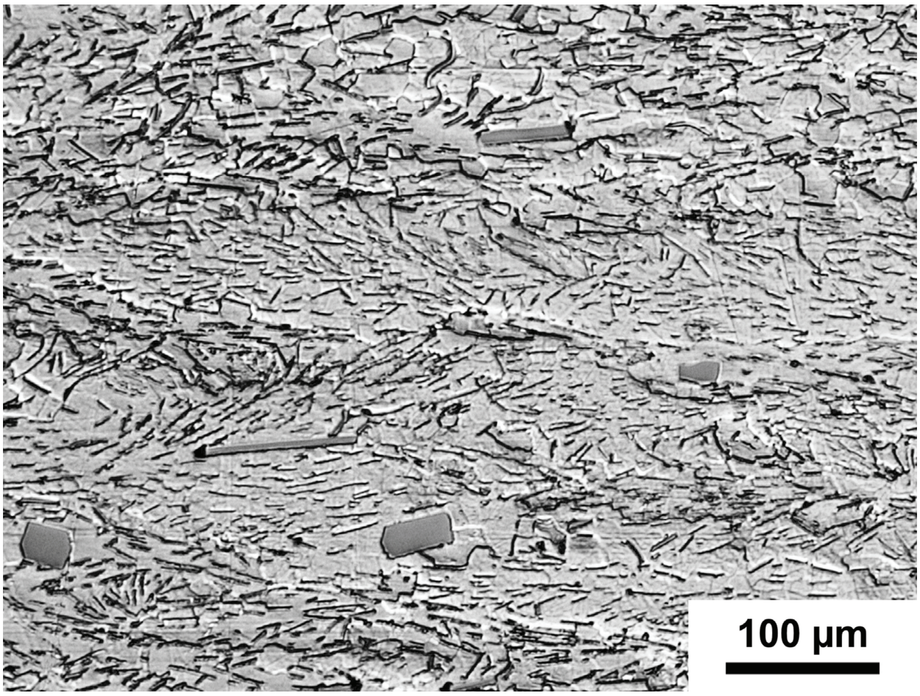
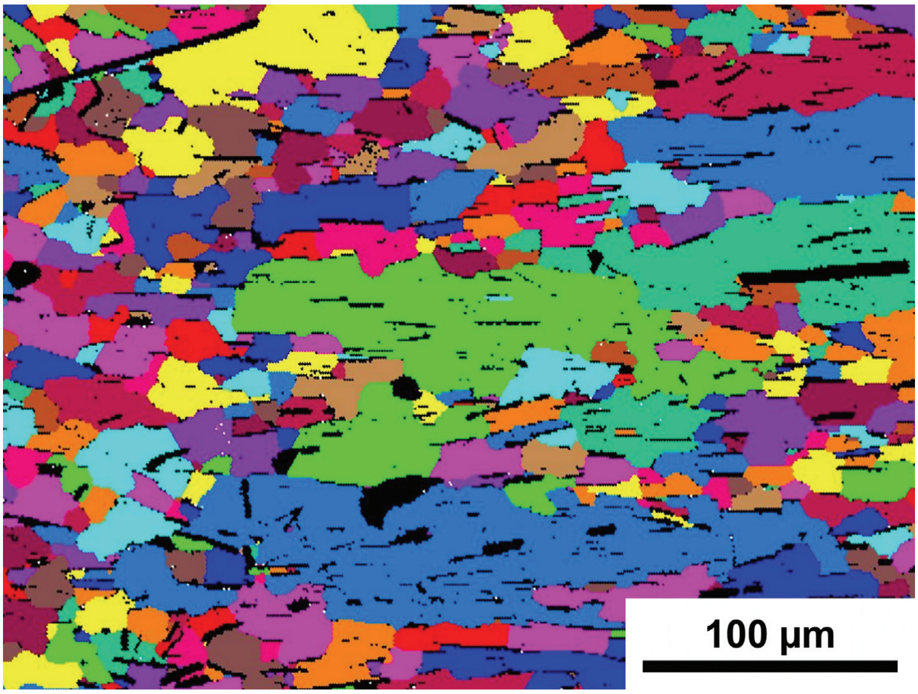


Fig. 3 Aluminium carbide particles in the casting

Fig. 4 Microstructure of the laboratory rolled sample



a) carbides – unetched state



b) grains of α-FeAl, made visible by the EBSD method